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INITIAL CENTRIFUGE TESTS OF A SUBJECT CONTROLLABLE ANTI-G VALVE

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ABSTRACT - A subject controllable anti-G valve (SCV) has been built and tested during an initial series of centrifuge runs. Outlet pressure from the SCV is controllable over the range of 0-12 psi with a maximum flow rate of 13 SCFM. During three gradual onset rate (0.1, 0.2, 0.4 G/sec) ramps to 5 GZ, the subjects selected opening points (1.6 to 1.64 Gz) and G-suit pressures (5.1 to 5.3 psi at 5 GZ) that were within the allowable limits defined by the standard military specification (MIL-SPEC). For 30 sec duration plateaus the mean G-suit pressures preferred by the subjects were 0.8 psi at 3 Gz, 2.8 psi at 4 Gz and 5.3 psi at 5 Gz. These values are significantly lower than the mid-range value of the MIL-SPEC at 3 and 4 Gz and slightly higher than the mid-range value at 5 Gz. The MIL-SPEC requires 2.0, 3.5, and 5.0 +/- 0.6 psi at 3, 4, and 5 Gz respectively. They decreased their G-suit pressure during the 30 sec plateau at 3 Gz but at 5 Gz selected a slight increase in pressure during the latter part of the plateau. The results are preliminary and additional testing at higher Gz levels and onset rates is recommended.

INTRODUCTION - Pilots flying highly maneuverable aircraft are frequently exposed to increased Gz accelerations. The inertial force resulting from Gz acceleration tends to displace blood away from the head and toward the legs. The result to the pilot may be greyout, blackout, or even loss of consciousness. The typical Gz protection system consists of the anti-G suit and the anti-G valve. The anti-G suit is a garment with pneumatically inflatable bladders that are designed to compress the pilot's abdomen, thighs, and calves and thereby retard blood pooling in the lower body and aid in maintaining head level arterial blood pressure (5). Pressure in the anti-G suit is automatically regulated by the anti-G valve. The typical anti-G valve has a mechanical sensing element that opens the valve at some set Gz level (i.e., 1.5 Gz) and adjusts the suit pressure as a function of the Gz level (i.e., 1.5 psi/Gz). G-valve characteristics are defined as a military specification (4). The increased tolerance afforded the pilot by this system is 1 to 1.5 Gz. Hallenbeck (2) describes numerous G-suits and G-valves that were tested or in use during the 1940's. The range of opening points used was from 1 to 4 G and inflation schedules from 0.8 to 2.2 psi/G. Burton et. al. (1) reported an additional 0.4 Gz tolerance increase over the standard inflation schedule by pre-inflating the G-suit to 1.0 psi before the onset of G and increasing the suit pressure at peak G by about 50%. It is possible that other criteria, in addition to the opening point and Gz level, should be considered in the determination of the ideal G-suit pressure. Whereas the current generation of mechanical anti-G valves respond only to the Gz level, it is possible to design an advanced electronic anti-G valve to regulate G-suit pressure based upon a variety of inputs. Such inputs might include onset rate, anticipated peak Gz, time at Gz, recent Gz time history, individual variability, comfort, performance, and physiological status. Revisions to the specifications that define G-valve performance would also be required.

This report describes a test device developed to control anti-G suit pressure as an initial series of centrifuge tests using the device as a closed loop subject controlled anti-G valve (SCV).

METHODS

Anti-G Valve - It was our goal to construct an experimental anti-G valve that could be controlled either closed loop by the subject during a G profile or externally by an experimenter or computer. A bellofram Type 1000 current-to-pressure transducer (I/P) and two Bellofram Type 75 relays were utilized to control the air pressure to the anti-G suit (CSU-13B/P). The connections are shown in Figure 1. The I/P is an electropneumatic device providing an output pressure of 3 to 15 psig that is directly proportional to an electrical input signal of 4-20 ma. It uses a supply pressure between 18-100 psig. In this study a supply pressure of 75 psig was used. The system provides a maximum flow of 13 standard cubic feet per minute (SCFM). The subject varied the pressure in the anti-G suit by controlling the current (I) to the I/P transducer. This was accomplished by means of a hand-held potentiometer which varied the signal to a Darlington transistor current amplifier. The amplifier's output was connected to the current coils of the I/P transducer. Therefore, changing the potentiometer setting varied the current to the I/P transducer whose output pressure in turn controlled the amount of pressure fed from the air supply through the relays to the anti-G suit. A 0-15 psig pressure transducer was connected between the anti-G suit and the paralleled Bellofram relays to monitor suit pressure.

Equipment - The tests were conducted on the Dynamic Environment Simulator (DES), a man-rated three axis centrifuge. The DES cab was configured with a standard aircraft seat mounted at a 30° seat back angle. A semi-circular light bar was mounted at eye level to monitor the subject's peripheral field of view (FOV). The light bar consisted of 120 light emitting diodes (LEDs) spaced at 1.5° apart to define an arc of 180°. For these tests 13 pairs of LEDs are centered at 45° either side of the bar center point (90° +/- 18° FOV) were sequentially illuminated. Each pair of LEDs was turned on for 0.07 second in each cycle (0.875 sec per sweep). During all runs the subjects had a hand-held, one-turn potentiometer which allowed them to control the G-suit pressure over the range 0 to 12 psig.

Procedures - Eight experienced subjects from the Sustained Acceleration Test Panel participated in this experiment. All of the subjects were familiar with the standard G-suit and valve; one was a rated USAF pilot. Each subject participated in six runs on the DES. All runs were conducted in a single session and were presented in the same order to each subject. The subjects were instructed that

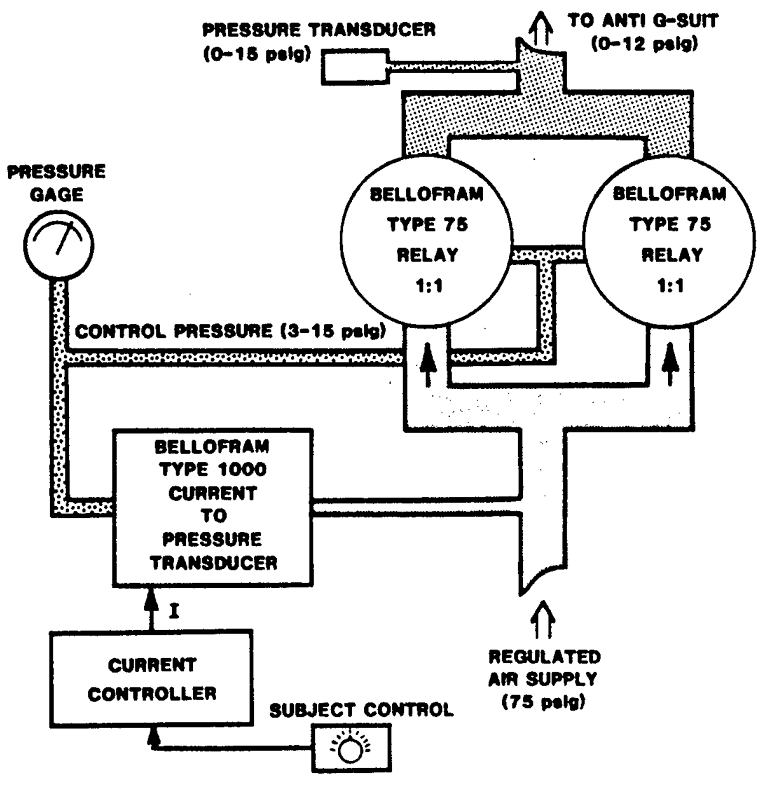

Figure 1. SUBJECT CONTROLLABLE ANTI-G VALVE.

throughout the runs they were to use the hand-held controller to adjust the pressure in the G-suit to their preference. Also, if at any time they lost peripheral vision (90° +/- 18° FOV) they were to terminate the run via a stop switch. The first three Gz runs of a session (series 1) consisted of gradual onset ramps (GOR) of 0.1 G/sec, 0.2 G/sec and 0.4 G/sec. Each ramp started at 1 Gz and terminated at 5 Gz. The second series of three runs consisted of a 0.5 G/sec onset ramp to 30 sec plateaus at 3, 4, and 5 Gz respectively. They were allowed a rest period of at least 60 sec at 1 Gz between each of the six G exposures. A primary concern during these initial runs was to determine the feasibility of allowing the subjects to use the SCV to command safe levels of G-suit pressure. For this reason the subjects were briefed before the test as to the G levels and sequence of the runs.

Statistical Analysis - Analyses of variance (ANOVA) were performed using the opening point (the Gz level at which the subject first dialed in G-suit pressure) as the dependent variable with factors subject and onset rate or Gz level. ANOVAs were also performed using the G-suit pressure difference between that chosen by the subjects and that specified by military specification (MIL-SPEC) as the dependent variable with factors subject, Gz level, and either onset rate or time at plateau. Statistical significance was set a $p \leq 0.05$. T-tests were used for pairwise comparisons.

RESULTS - Because of the preliminary nature of these tests, the subjects were all exposed to the same sequence of stress environments. This lack of randomization and the subjects' prior knowledge of the Gz levels limits the interpretation of the results.

Opening Point - The mean Gz levels at which the subjects first selected G-suit pressure are shown in Table I. There was no significant difference in the opening points selected by the subjects among the three GOR runs (series 1). In series 2 the mean opening point selected for the 3 Gz plateau level was significantly higher than that selected for either the 4 Gz or the 5 Gz levels. The opening point data for series 2 was probably influenced by the subjects' prior knowledge of the Gz levels (i.e, G-suit pressure was initiated sooner for the 5Gz run than for the 3Gz run).

Forty-eight total runs were conducted (8 subjects x 6 runs). In fourteen runs (29%), the subjects commanded some level G-suit pressure (greater than 0.2 psi) at 1 Gz before the Gz level increased. There was a wide variation among the subjects for all parameters.

TABLE I. OPENING POINTS SELECTED BY THE SUBJECTS

	Series 1 (GOR)		
Onset Rate (G/sec)	0.1	0.2	0.4
Opening Point (Gz)	1.64 ±0.63	1.64 ±0.89	1.60 ±0.76
	Series 2 (30 sec plateaus)		
Plateau Level (Gz)	3.0	4.0	5.0
Opening Point (Gz)	1.96* ±0.82	1.40 ±0.69	1.39 ±0.48

Values are mean Gz opening point ± standard deviation (S.D.).
* significantly different than either 4 or 5 Gz

TABLE II. SUBJECT SELECTED G-SUIT PRESSURES

Series	Onset rate (G/sec)	Gz 2	3	4	5
1	0.1	1.20 ± 0.81	2.10 ± 1.30	3.61 ± 1.57	5.31 ± 1.52
1	0.2	1.15 ± 1.16	2.67 ± 1.73	3.76 ± 1.86	5.31 ± 2.04
1	0.4	0.96 ± 0.96	2.36 ± 1.72	3.54 ± 1.91	5.11 ± 1.67
2	0.5	---	0.83 ± 0.72	---	---
2	0.5	---	---	2.75 ± 1.09	---
2	0.5	---	---	---	5.31 ± 1.17
	MIL-SPEC	0.50 ± 0.50	2.00 ± 0.60	3.50 ± 0.60	5.00 ± 0.60

Values are mean psi ± s.d. Series 1 data are mean G-suit pressures recorded during the acceleration ramp at the identified Gz levels. Series 2 data are mean pressures for the 30 sec plateaus at those Gz levels.

TABLE III. G-SUIT PRESSURES DURING 30 SECOND PLATEAUS

Gz	MIL-SPEC	Time Epoch 0-10 sec	11-20 sec	21-30 sec	0-30 sec
		(subject selected G-suit psi mean ± s.d.)			
3.0	2.0	1.16 ± 0.90	0.81 ± 0.86	0.51 ± 0.64	0.83 ± 0.72
4.0	3.5	2.92 ± 0.89	2.80 ± 1.18	2.51 ± 1.35	2.75 ± 1.09
5.0	5.0	5.24 ± 1.01	5.37 ± 1.18	5.32 ± 1.61	5.31 ± 1.17

G-Suit Pressure - The mean G-suit pressures elected by the subjects are presented in Table II. Values are also included on the pressure required by the current MIL-SPEC at vairous Gz levels. The present MIL-SPEC for the high flow G-valve requires the valve opening point to be between 1.25 and 1.5 Gz with an increase of pressure of 1.5 psi per Gz. The correct suit pressure required by the MIL-SPEC may be defined by the formula: G-suit psi =[(1.5 x Gz) - 2.5]. It should also be noted that the MIL-SPEC allows +/- 0.6 psi as allowable suit pressure at various Gz levels.

Time at G - The G-suit pressure was also examined for the three 10 sec time periods during the 30 second plateau runs. Values presented are the mean pressures for each of the 10 sec epochs. The changes were not statistically significant. The results are presented in Table III.

DISCUSSION - There were no differences in the opening points selected by the subjects for the three GOR conditions. Also the mean G-suit pressures selected by the subjects during the three ramps were nearly identical and were within the allowable limits of the MIL-SPEC (Figure 2). Although each onset rate was increased by a factor of two (i.e., 0.1, 0.2, 0.4 G/sec), these rates could all be classified as gradual. Tests with rapid onset rates (> 3G/sec) should be conducted.

There was a wide variation in the G-suit pressures selected by the individual subjects during the series 2 plateau runs (Figure 3). At 3 and 5 Gz the subjects preferred significantly less pressure than the MIL-SPEC mid-range value, while at 5 Gz they preferred slightly more pressure. The slope of the three preferred pressures is 2.2 psi/G. The standard increase is 1.5 psi/G

These results imply that at higher Gz levels (> 6 Gz) subjects may prefer more G-suit pressure than that now provided by the standard anti-G valve. At 3 and 4 Gz the subjects preferred less pressure as the 30 sec plateau continued but at 5 Gz slightly more pressure was selected as the plateau continued (Figure 4). The cardiovascular reflexes, which became effective after 6-10 sec at peak G, may be sufficient at the lower G levels to allow the subjects to reduce their G-suit pressure (3).

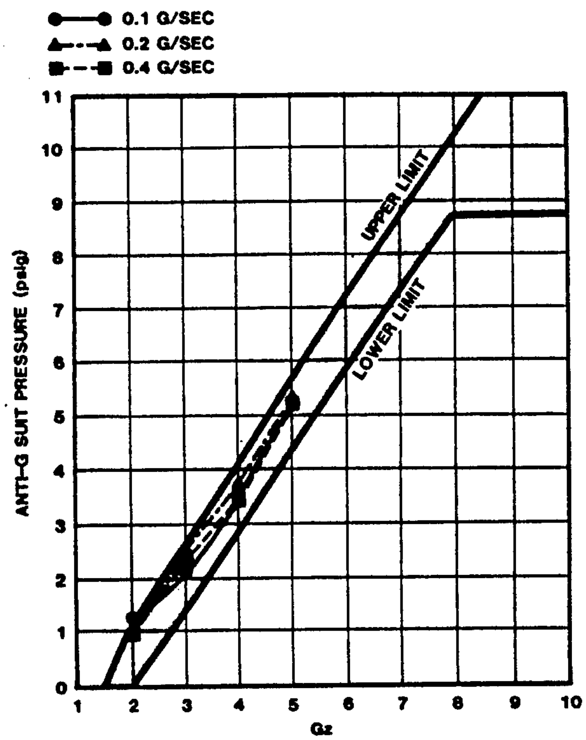

Figure 2. RESULTS OF THE SERIES 1 RUNS AND THE ALLOWABLE LIMITS OF THE MILITARY SPECIFICATION.

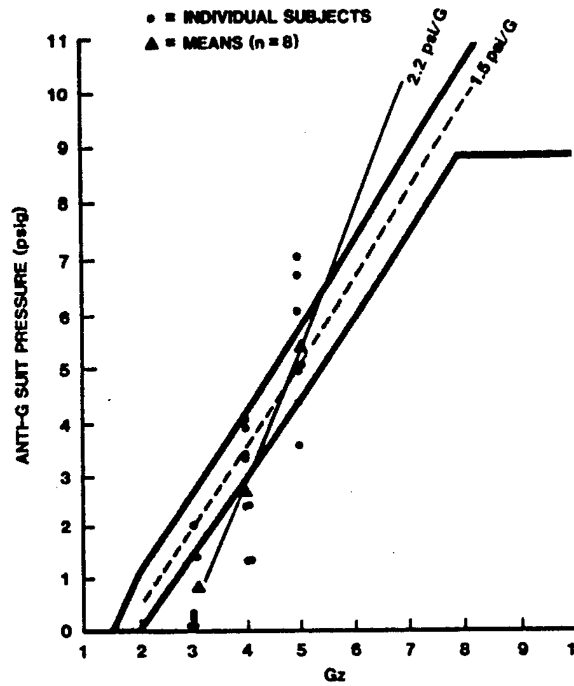

Figure 3. RESULTS FROM SERIES 2 COMPARING THE INDIVIDUAL SUBJECTS AND THE MEANS AGAINST THE STANDARD MILITARY SPECIFICATION.

All of the subjects stated that the SCV allowed them good control of their G-suit pressure. The liked using the SCV. Four of the subjects remained relaxed for all of the runs. The others performed an each M-1 (est 25-50% of maximum effort) straining maneuver during some of the profiles, primarily at 5 Gz. No runs were aborted and no subject lost peripheral vision (90° FOV). Future experiments are planned using the SCV and higher Gz levels, rapid onset rates, and longer duration simulated aerial combat maneuvering profiles.

CONCLUSIONS - A SCV has been built and tested on the centrifuge with a high level of subject acceptance. The subjects selected opening points (1.6 to 1.64 Gz) and G-suit pressures (5.1 to 5.3 psi at 5 Gz) during three gradual onset (0.1, 0.2 and 0.4 G/sec) runs to 5 Gz that were within the allowable range of the standard MIL-SPEC. The mid-range G-suit pressures defined by the MIL-SPEC at 3, 4, and 5 Gz at 2.0, 3.5, and 5.0 psi respectively. During these tests, for 30 sec plateaus at 3, 4, and 5 Gz, the mean G-suit pressures selected by the subjects were 0.8, 2.8, and 5.3 psi respectively. These values are significantly lower than the MIL-SPEC at 3 and 4 Gz and slightly higher at 5 Gz. Less G-suit pressure was selected by the subjects at 3 and 4 Gz at the 30 sec plateau runs continued while they increased their G-suit pressure slightly at 5 Gz. These results are preliminary and randomized testing at higher Gz levels with rapid onset rates is recommended.

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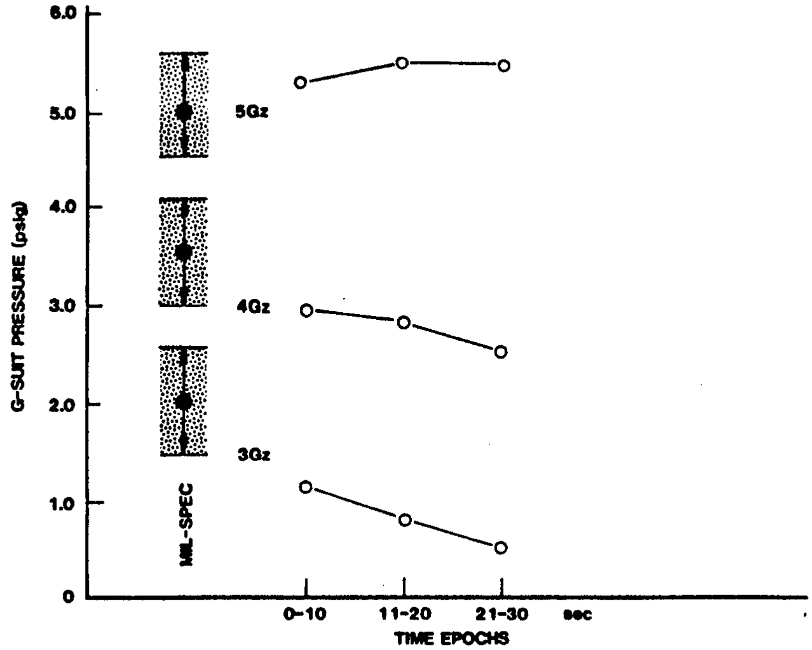

Figure 4. SUBJECT SELECTED G-SUIT PRESSURES DURING THE 30 SECOND PLATEAU RUNS AT 3, 4, AND 5 Gz. VALUES ARE ALSO INCLUDED FOR THE MIL-SPEC AT 3, 4, 5 Gz.

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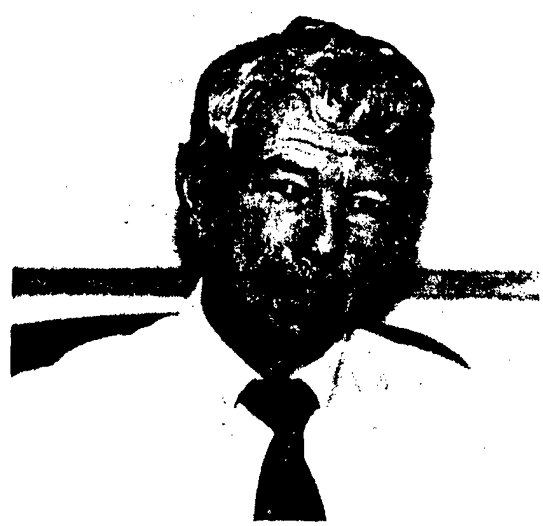
BIOGRAPHIES

John W. Frazier is a research physiologist at AAMRL/BBS, Wright-Patterson AFB, OH. He has extensive experience in centrifuge operations and as an investigator in acceleration research. He has served as a subject in over 100 centrifuge runs. Mr. Frazier is a graduate of Wilmington College.



John W. Frazier

William G. Gruesbeck earned his Bachelor of Science Degree in Mechanical Engineering from Purdue University. He joined Raytheon Service Company in 1981 as a systems engineer to provide engineering support for the mechanical systems and experimental protocols for the Dynamic Environment Simulator. He holds several patents and is a Registered Professional Engineer in the State of Ohio. He is presently assigned to the COBRA DANE over the horizon radar system.

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Lawrence H. Gould has been involved in the support of research and development programs since joining Raytheon Company in 1961. He has earned a Bachelor of Science Degree in Computer Science from Wright State University in Dayton, Ohio. Since 1976, he has been directly involved in the operation, maintenance and engineering support for the Dynamic Environment Simulator (DES), a three axis, man-rated centrifuge in the Armstrong Aerospace Medical Research Laboratory at Wright-Patterson AFB, Ohio. He is presently Raytheon Service Company's Program Manager for the DES.

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TABLE OF CONTENTS

FEATURES

DEPARTMENTS